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TNO Prins Maurits Laboratory

Development of directives for safe storage of ammunition and explosives for military operations out of area.
Phase 1: Problem definition and evaluation of present directives.

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De Nederlandse strijdkrachten nemen steeds vaker deel aan crisisbeheersingsoperaties ‘out of area’. Eén van de potentiële gevaren wordt onder andere gevormd door de veldopslag van munitie en explosieven. Omdat bij militaire operaties de veiligheid van de eigen eenheden centraal staat, dienen de gevolgen bij een eventuele calamiteit met een opslagdepot voor de directe omgeving beperkt te blijven. Daarom worden strikte regels voorgeschreven, waarin onder andere minimale afstanden tot potentiële explosiebronnen worden vermeld. De organisaties waaronder militaire operaties worden uitgevoerd (NATO/UNO) zijn echter niet eenduidig in hun regelgeving. Daarnaast zijn er ook nationale regelgevingen die op sommige explosieveiligheidsaspecten van elkaar afwijken.
In opdracht van de KL en KLu, heeft het TNO Prins Maurits Laboratorium (TNO-PML) een onderzoeksprogramma opgestart, waarin eenduidige, militair toepasbare, richtlijnen voor veldopslag van munitie en explosieven worden ontwikkeld. Dit programma is onderverdeeld in vier fasen. In de eerste fase worden de tekortkomingen van de huidige richtlijnen geïnventariseerd en is een programma van eisen van de KL en KLu samengesteld. Tevens wordt de problematiek omtrent de veldopslag van munitie en explosieven nader gedefinieerd. In de tweede fase van het project wordt de opgedane kennis en informatie gebruikt om voorlopige richtlijnen te formuleren die in de derde fase geëvalueerd worden op aspecten als explosieveiligheid en militaire uitvoerbaarheid. In de vierde fase zullen definitieve richtlijnen worden opgesteld.
In de eerste projectfase, beschreven in dit rapport, wordt allereerst ingegaan op de algemene problematiek omtrent veldopslag van munitie en explosieven. Hierbij blijkt dat explosieveiligheidsaspecten al gauw in conflict komen met de militaire toepasbaarheid van de regelgeving. Het voorschrijven van minimale ‘veiligheids’-afstanden tot potentiële explosiebronnen, waarbij bepaalde gekwantificeerde risico’s ingecalculeerd zijn, betekent in veel gevallen dat munitiedepots buiten een bivak opgesteld moeten worden, terwijl een commandant de voorkeur uitspreekt voor opslag in het bivak. Een acceptabel compromis tussen explosieveiligheid en militaire toepasbaarheid dient voor de toekomstige regelgeving gevonden te worden.
Ten tweede is een programma van eisen van de KL en KLu opgesteld, waarbij de voorkeur is uitgesproken voor een modulaire opslag van de munitie en explosie-

ven. De goederen worden in TEU-containers vervoerd, die tevens de basis vormen van één opslagmodule. Eén container bevat explosieve goederen met een netto gewicht tussen 500 kg en 5000 kg. Daarnaast is door de KL en KLu een geaccepteerd risico gedefinieerd, dat overeenkomt met wat op dit moment voorgesteld wordt door de NATO AC/258 groep. Verwacht wordt dat de implementatie van dit (relatief lage) risiconiveau in de toekomstige richtlijnen, de militaire uitvoerbaarheid aantast.
Ten derde is de huidige regelgeving op het gebied van veldopslag van munitie en explosieven geïnventariseerd. De NATO Allied Ammunition Storage and Transport Publication, AASTP-1, beveelt richtlijnen aan die met name van toepassing zijn voor permanente opslag met een minimaal risico voor de omgeving. Een apart hoofdstuk is gewijd aan veldopslag voor militaire operaties 'out of area'. Het handboek is meer een standaard voor bureaugebruik, dan een militair voorschrift voor gebruik in het veld. Daarnaast is het hoofdstuk voor veldopslag niet optimaal toegespitst op de eisen en wensen van de KL en KLu. De militaire richtlijnen die door de VN worden voorgeschreven, zijn niet eenduidig en onvolledig. Het resulterende beschermingsniveau voor personeel en omgeving is aanzienlijk lager dan het geval is bij opvolging van de NATO-richtlijnen.
Ten vierde wordt een introductie van de volgende fasen van het project gegeven. Hierin wordt voorgesteld om in de tweede fase, met behulp van de nu vergaarde kennis en informatie, voorlopige richtlijnen te formuleren, die met name gebaseerd zijn op explosieveiligheidsaspecten. Ook de toegankelijkheid van de richtlijnen, wat vooral belangrijk is voor gebruik in het veld, heeft speciale aandacht. In de derde fase van het project wordt de militaire uitvoerbaarheid getoetst en worden de richtlijnen zonodig aangepast. Mogelijke maatregelen om veiligheidsafstanden te reduceren en daardoor de militaire toepasbaarheid te vergroten zijn aangegeven.

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Abbreviations

BLAHA	Basic Load Ammunition Holding Area
CG	Compatibility group
DDESB	Department of Defence Explosives Safety Board
ES	Exposed Site
ESTC	Explosives Storage and Transport Committee
HE	High Explosive
HD	Hazard Division
IBD	Inhabited Building Distance
IWP	Informal Working Paper
NATO	North Atlantic Treaty Organization
NEQ	Net Explosive Quantity
NEW	Net Explosive Weight
OP	Observation Post
PES	Potential Explosion Site
POL	Petroleum, Oils, Lubricants
PTRD	Public Traffic Route Distance
Q-D	Quantity-Distance
RNLA	Royal Netherlands Army
RNLAF	Royal Netherlands Air Force
UN	United Nations
UNPROFOR	United Nations Protection Force
UNTAC	United Nations Transitional Authority in Cambodia
TO	Theatre of Operations
WP	Working Paper

1 Introduction

The Royal Netherlands Armed Forces are frequently called upon to participate in military missions during international crisis situations. The safety of personnel and environment during missions out of area takes a high priority. The safe transport and storage of ammunition and explosives is one of the issues involved. It is obvious that the demands for field storage out of area differ from those for permanent storage in the interior zone. The mandate of the mission, as well as the infrastructure and the climate of the area are variable, demanding a flexible approach in guidelines for semi-permanent field storage of ammunition and explosives.

Worldwide there are several standards on explosion safety principles which prescribe guidelines for safe transport and storage of ammunition and explosives. The Ministry of Defence of the Netherlands has established the Military Publication MP 40-20 (1995), in which directives for permanent storage in the interior zone are presented. The publication does not include additional guidelines on field storage of ammunition and explosives for use during missions out of area.

The NATO 'Allied Ammunition Storage and Transport Publication', AASTP-1, was established by a forum of NATO members and it may be used by all NATO members. The manual includes a separate chapter on field storage of ammunition and explosives. Because the information is very detailed and not very accessible, the manual is less suitable for direct application in the field.

On the other hand, Forces operating under the flag of the United Nations, like the former U.N. Protection Forces (UNPROFOR), are forced to use Logistics Directives established by the U.N. Headquarters. The regulations prescribed in these Logistic Directives are straightforward. However, according to the Dutch Key Delegate of the NATO Storage Subgroup AC/258, the guidelines prescribed are insufficient and/or inconsistent and therefore not adequate regarding explosion safety principles (Kostermans, 1994).

Therefore, on behalf of the RNLA and RNLAF, TNO-PML has started a research programme with the aim to develop military applicable guidelines for safe semi-permanent field storage of ammunition and explosives. The research programme is subdivided into four phases. In the first phase, current directives are evaluated and a list of the specific needs and demands of the RNLA and RNLAF is formulated. In the second phase, preliminary guidelines will be formulated with the information obtained in the first phase. The third phase is reserved to evaluate alternative field storage concepts on explosion safety aspects and military applicability. In the fourth phase, a final concept will be formulated.

This first interim report presents the results of the first phase of the research programme. The report starts with a detailed problem definition on field storage of ammunition and explosives out of area, including all basic factors determining the level of risk involved. In Chapter 3, the specific demands and needs of the RNLA and RNLAF are inventoried, including a definition of the accepted level of risk. In Chapter 4, available international directives are evaluated on the base of a fictitious field storage case. Also, the discussion by the AC/258 Storage Subgroup on the subject is summarized. This interim report ends with an introduction to the next phases of the project.

2 Problem definition

2.1 Introduction

The demands on storage of ammunition and explosives out of area are different to those for permanent storage. In the case of permanent storage, explosion safety principles and the conditioning of the stored goods have priority, while non-permanent field storage out of area also includes operational flexibility in order to fulfil a particular mission. As a result, the accepted risk regarding explosion safety inevitably increases. Therefore, guidelines for field storage of ammunition and explosives should prescribe a well-considered compromise between the accepted level of risk and the operational flexibility. The balance between explosion safety principles and military operational flexibility is defined by the type of mandate:
- peacekeeping;
- peace-enforcing (troops are impartial);
- wartime (troops are partial).

During peacekeeping missions, the survival of troops is paramount, which means that safety principles for military activities have priority. During peace-enforcing missions, the permanent quality of military equipment, including ammunition and explosives, is highly important. During wartime, this quality has the highest priority, resulting in the highest accepted level of risk. Although essential in the development of guidelines for field storage, the total levels of risk are difficult to define and quantify. Since Field Commanders often emphasize military operational flexibility and trivialize explosion safety principles, current practical situations are probably worst cases when explosion safety aspects are considered.

Because each mission out of area will meet unique circumstances in the field, situations may and will occur in which a Field Commander has to deviate from standard guidelines to fulfil a mission. Therefore, an important aspect in the development of guidelines is that they should include sufficient information about the consequences regarding explosion safety. Only then is the Field Commander optimally informed to take well-considered decisions.

Another important aspect in the further development of guidelines is the conditioning of the stored goods. The ammunition and explosives should remain operational during a long period of time in all kinds of environmental conditions, like extreme cold, heat or humidity. Also, the guidelines should be user-friendly and above all, consistent. Summarizing, there are five aspects on which the development of guidelines should be based:

1 explosion safety principles;
2 operational flexibility;
3 inclusion of alternative concepts and corresponding risks;
4 storage conditioning;
5 user-friendliness of guidelines.

In the following sections, the above-mentioned aspects are discussed in more detail to collect all the relevant information of value for this study and to search for parametres which have a great influence on the regulations to be developed.

2.2 Explosion safety principles

In general, the level of risk is defined as the probability of an explosion multiplied by the resulting damage and injuries. On the one hand, the chance that an explosion will occur cannot be exactly quantified. However, the factors affecting this chance can be qualified and therefore be used to minimise this chance. On the other hand, the explosion effects and the level of damage and injuries in case of an explosion can be quantified with the help of empirical formulas, which were particularly based on data obtained from bombardments in the UK during World War II.

In this section, the factors affecting the total level of risk and the way they are accounted for in explosive safety standards are presented. The factors are subdivided into specific groups of interest. These groups are: the type of threats defining the chance of an accidental or intentional explosion, the resulting explosion effects and the damage to the environment depending on PES and ES specifications and their interior and exterior distances.

The types of threats that determine the chance that an *accidental* explosion will occur are successively:

- natural threats:
  - fire;
  - lightning;
  - extreme weather conditions (cold, heat, rainfall);
  - storm;
  - snow/ice-formation;
  - etc.;
- human factors:
  - accidents during the handling of ammunition and explosives;
  - violation of smoking ban;
  - inattention.

Most standards on explosion safety principles include regulations to reduce these natural and human threats. Especially precautions for lightning and extreme weather conditions and fire-fighting are given.

Military threats which can cause an *intentional* explosion are successively:
- air attack, i.e. gun fire, bombs, guided missiles;
- ground attack, i.e. high- or low-angle firing;
- sabotage/pilferage.

It is not the intention of explosion safety standards to give advice to reduce these military threats.

The chance of being hit depends on:
- layout of storage site;
- dimensions of storage facility or site;
- visibility of storage facility or site (camouflage);
- security at storage site;
- defence of storage site;
- military equipment of enemy;
- time of exposure.

To reduce the enemy threats and the chance of being hit, Field Commanders often store their basic load ammunition inside the cantonment. In this situation, they accept the consequences of an explosion. In case of a mass explosion of HD1.1 ammunition, the explosion effects for all PES's are:
- projections:
  - fragments from the ammunition;
  - debris from the structural material;
  - if applicable, debris from earth cover;
  - ejecta from the crater;
- air blast;
- thermal radiation;
- ground shock.

The explosive safety standards emphasize air blast and projections. Projection hazards are mostly subdivided into primary fragments (i.e. casing of ammunition and fragments from the storage facility) and secondary fragments (formed as a result of high blast pressures on structural components in close proximity to the explosion).

The factors affecting the severity of these explosion effects are:
- Hazard Division (HD) of ammunition and explosives stored;
- Net Explosive Quantity (NEQ) of ammunition and explosives stored;
- strength of magazine:
  - constructive design (i.e. open stack, container, truck, armoured vehicle, earth-covered);
  - material (i.e. concrete, steel, wood, soil, lightweight material);

  - dimensions and geometry;
- intermagazine distance (interior distance);
- distance between Potential Explosive Site (PES) and Exposed Site (ES) (exterior distance).

In ammunition and explosives safety standards, so-called protection levels are defined, which are quantity-distance functions corresponding to a certain strength of air blast, mass fire (for HD1.3 ammunition) and resulting damage and injuries to be expected. Because projection hazards from a PES cannot be related to the scaled distance, minimum distances and (less founded) expected hazards are defined. For small amounts of ammunition and explosives, the explosion hazards are particularly determined by primary and secondary fragments.

The level of damage to the environment and injuries depend on the vulnerability of the exposed site. In ammunition and explosives safety standards, ES's are subdivided into vulnerability classes and related accepted levels of risk (= damage and injuries), i.e.:
- inhabited buildings, barracks, sleeping accommodation;
- airfield, hospital, POL installations, civilian population;
- public traffic routes;
- other explosive sites.

In this study it is evident to search for measures to reduce the chance of an accidental or intentional explosion as well as to reduce the explosion effects and thus the level of damage without affecting the operational flexibility. One of the most obvious measures is to place barricades around a storage magazine or site.
On the one hand, such a facility protects the site against threats and reduces the chance of being hit; on the other hand, if the stored goods in a magazine do explode, barricades can avoid sympathic detonation of acceptor magazines, and they reduce the explosion effects. It is essential that barricades provide protection for horizontal as well as vertical threats (i.e. mortar artillery).

2.3 Operational flexibility

The application of explosion safety principles may not put the operational flexibility at risk. The guidelines must be applicable to the military and must allow military units to fulfil their mission. In the context of this study, the preservation of operational flexibility and military applicability stands for:
1 accessibility of ammunition and explosives;
2 possibility to secure and defend the field storage site;
3 rapid construction and demolition time of the storage site;
4 easy construction by unskilled personnel;
5 use of logistics-friendly construction materials.

Particularly the first two points are often in conflict with the general explosives safety principles. While regulations prescribe a minimum distance for barracks to potential explosion sites of, for instance, 400 m, the surface area of a cantonment is perhaps only 200x200 m^2. In the case of the storage of relatively small amounts of ammunitions, the Field Commander does not want to arrange a separate storage site, since a separate storage site:
- needs extra guards;
- is less accessible;
- is an ideal target for snipers/sabotage/pilferage.

The first two points are in conflict with the desired operational flexibility, while the third point exposes the stored goods and the security personnel to danger. Although a separate storage site would create a safer situation for personnel and material inside a cantonment, in practice, the Field Commander will locate the storage site inside the cantonment.

The conflict between operational flexibility and explosive safety principles will have a major influence on the development of future regulations. It makes no sense to prescribe minimum quantity-distances which will not be observed. Therefore, measures should be developed to reduce the minimum quantity-distances and/or the regulations should include sufficient information about the consequences when the standard regulations cannot or will not be observed.

2.4 Flexibility of guidelines

When a Field Commander can comply with the regulations prescribed, the level of risk is more or less known and accepted. However, if there are situations in which a Field Commander has to deviate from the standard regulations, it is hard to quantify the increase (or decrease) in risk regarding explosion safety. The (relatively) quantification is necessary in order to make well-considered decisions. The NATO standard AASTP-1 has reserved a section in which the 'Injury and damage to be expected at different levels of protection for HD 1.1 and grouping of structures and facilities' are discussed (AASTP-1, page I-4-37 to I-4-52). As a function of scaled distances it presents the expected projection hazard and blast effects of open stacks and light structures and the resulting injuries of personnel and damage to facilities. This information is of value for Field Commanders. However, it would be preferable to present the information in a graphical format which makes the information more accessible to users. One of the tasks of the second phase of this study is to develop such a format.

Standard manuals for transport and storage of ammunitions and explosives, like the NATO AASTP-1 or U.S. DoD 6055.9-STD, contain all the information to create an accepted level of risk regarding explosion safety. However, they are developed for use at office level, where the accessibility of the information has

less priority. On the contrary, a Field Commander wants relevant information quickly, straightforwardly and preferably written on just a few sheets. The UN Logistics Directive 312, used by the former UNPROFOR, is an example of such a 'field' regulation. As mentioned earlier, the consistency of this directive is under discussion in the AC/258 subgroup. It shows that it is difficult to comply with all requirements mentioned in this chapter and still formulate the directives in a user-friendly direct accessible format. This aspect should also be accounted for in developing guidelines.

2.5 Storage conditioning

The conditions in which the ammunition and explosives are stored should not influence their quality. The stored goods must remain operational during the mission and after the mission when they are returned to the home country. Therefore, the stored goods must be protected against weather conditions like extreme cold, heat, rainfall or the effects of thunderstorms. The storage conditions of ammunition and explosives are specified on certain subjects, like the temperature range and maximum humidity. A frequently used measure to condition the atmosphere in a magazine is the use of ventilators and/or venting holes. When extreme heat (and humidity) becomes a major problem, extra insulation arrangements have to be taken.
Besides external factors, the stored goods should be kept free from dirt and mud. The use of pallets to stack the ammunition is an example of a measure to create ventilation between the ammunition and to keep the ammunition free from the floor, and thus dirt and mud.

3 List of needs and demands

3.1 General needs and demands

The goal of this study is to develop better guidelines for storage of ammunition and explosives in the field to be used by the RNLA and RNLAF. It is therefore necessary to define the specific needs and wishes of both forces. They are subdivided into several items for both the RNLA and RNLAF:

1 the storage concept;
2 the type of ammunition and explosives to be stored;
3 the selection of the storage site;
4 the selection of the storage facility;
5 the selection of protective measures;
6 accepted risk.

ad 1. The storage concept
To obtain a flexible approach on field storage regulations, a modular storage concept[1] is suggested by the RNLA and RNLAF. In this concept, a module is defined as one storage facility containing ammunition and/or explosives with a NEQ ranging from 500 kg to 5000 kg. Minimum interior and exterior quantity-distances (Q-Ds) should be prescribed on this basic concept. NEQs smaller than 500 kg need no regulations on minimum Q-Ds, since NEQs less than 500 kg are mostly basic load ammunition or explosives which must be kept in readiness in the vicinity of the operating units. The risk involved is accepted.
The explosion safety principles will be based on the assumption that the contents of only one module explodes at the time. In that case, the storage concept does not limit the total NEQ of ammunition and explosives of a storage site, since sympathic detonation of adjacent storage modules is prevented by adequate interior distances.

ad 2. Type of ammunition and explosives
The RNLA and RNLAF uses a wide variety of ammunition and explosives. It depends on the type of mission which ammunition has to be transported and stored in the field. In principle, all the ammunition and explosives used by the RNLA and RNLAF have to be considered. For transport and storage purposes, ammunition and explosives are classified into Hazard Divisions and Compatibility Groups. As a result, only these Hazard Divisions and the maximum net weight of explosives have to be considered.
A selection of ammunition often used by RNLA and RNLAF and other relevant storage information is presented in Table 1 (DMKL, 1995 and KLu, 1991). More

[1] This modular concept differs from the modular concept as often mentioned in American explosion safety standards.

than one type of ammunition per Hazard Division is presented to emphasis differences in packing volumes, gross and net weights.

Table 1: Selection of types of ammunition and additional storage information.

Description	Number per package	Volume (l) per package	Mass (kg) per package	NEQ (kg) per package	HD
SAA 5.56 mm M193	2000	26.4	20.0	3.7	1.4S
SAA.30 inch M1	1200	21.7	22.2	1.1	1.4S
SAA 7.62 mm NATO	920	24.2	32.5	2.8	1.4S
SAA 9 mm Ball	2100	18.2	32.3	0.9	1.4S
Hand-grenade, fragmentation, NR20C1	18	18.2	13.6	2.3	1.2F
Hand-grenade, offensive, NR17	18	18.2	12.6	3.7	1.2F
25 mm, NR112	800	1196	748	90	1.2E
Houwitzer 105 mm	32	1169	920	71	1.2E
Mortar 120 mm	32	984	870	156	1.1E
Cannon 120 mm	20	1151	932	39	1.1E
Houwitzer 155 mm	8	517	475	22	1.1D
DRAGON	8	2212	518	22	1.2E
TOW	9	1504	400	45	1.1E
Demolition kit, cratering, NR6	1	125	59.5	42	1.1D
20 mm HEI M56	200	37	59	10	1.2E
CBU Mk20	2	1196	685	91	1.1D
GP Mk82 500 lbs	6	1042	1406	523	1.1D
GP Mk84 2000 lbs	2	1516	1860	859	1.1D
GM HE MK8 Mod1	2	25	28	9.5	1.1D

ad 3. The selection of storage site

In practice, ammunition, explosives and POL installations are often stored inside relatively small cantonments (i.e. 200x200 m^2). Storage outside a cantonment is not desirable, because such a separate storage site needs extra security. Also, the stored goods and guards are potential objects of enemy fire (snipers). The wish to store the ammunition, explosives and POL installations inside a cantonment demands strict requirements on the aspect of explosion safety. Distances to sleeping accommodation, observation posts (OPs), etc. are small. This means that the ammunition and explosives need to be stored in adequate storage facilities or a higher risk should be accepted.

ad 4. The selection of storage facility

The ammunition and explosives are packed in specific packaging material and mostly transported in Twenty foot Equivalent Unit (TEU) or ISO-containers. These containers have dimensions of 6.09x2.43x2.62 m^3 (LxWxH), an internal volume of about 33 m^3 and a mass of about 2.2 tons. Their maximum carrying capacity is about 18 tons. UN directives prescribe a maximum NEQ of 5 tons of ammunition in these containers.

There are several field storage facilities used by the RNLA, depending on the amount of ammunition to be stored and the time of storage. Examples are constructions built with sandbags or a YPR (light armoured) vehicle.

Because the ammunition is transported in TEU-containers, it is desirable to use these as the basic storage facility. The advantage is that the stored goods do not have to be transferred to a YPR or bunker, introducing an extra risk. A container is considered as one stack module containing a maximum of 5 tons NEQ. An original TEU-container is qualified as a light structure, which offers no protection against a mass explosion of its contents or exterior military threats. Therefore, each container must be fortified or barricaded horizontally and vertically with protective measures to protect against external threats and to prevent sympathetic detonations to adjacent containers in the storage site.

ad 5. The selection of protective measures

The 'Handbook of Protective Constructions' (Van Leeuwen, 1993) of the RNLA describes several barricades to protect infrastructure or material against military threats. Some of these barricades can also be considered to protect ammunition and explosives storage facilities. Another requirement on the use of barricades for this specific application is that they reduce the explosion effects to the environment in case the contents of a module explodes.

Examples of types of barricades currently used by the RNLA are:

- Hesco Bastion blast wall;
- big bags filled with debris;
- walls of sandbags;
- TEU-container partially filled with sandbags.

These types of barricades only offer protection against low angle firing and limits explosion effects only in the horizontal direction. Therefore, a protective roof construction must be included in the presentation of suitable protective measures.

ad 6. Accepted risk

As mentioned earlier, the total risk, related to the storage of ammunition and explosives in the field, cannot be quantified exactly. In practice, the definition of risk is based on the quantification of damage levels and injuries to personnel in case one storage module explodes. The NATO AASTP-1 manual describes a number of protection levels for air blast and projection hazards, which include corresponding damage levels and injuries. This manual is consulted to determine an acceptable protection level for personnel, material and environment.

The policy of the RNLA and RNLAF is to keep the damage level and injuries to personnel as low as (military practicably) possible in the case of a mass explosion of one storage module. The following criteria on blast and projections are accepted by the RNLA and RNLAF. Other potential explosion hazards, like thermal radiation and ground shock, are not included, but must be considered in the further development of Q-Ds, especially in cases where the Q-Ds are small.

Blast criterion

For an open or lightly confined stack with HD1.1 ammunition, the accepted blast criterion is defined by the following Q-D function:

$$D = 9.6 . Q^{1/3} \tag{1}$$

According to the NATO AASTP-1 manual (Part I, §1.4.7.3 and §1.4.7.9), a scaled distance of $9.6Q^{1/3}$ corresponds to an expected peak incident overpressure of 16 kPa. The expected damage and injuries due to blast effects with this overpressure are:

- personnel may suffer temporary loss of hearing, permanent ear damage is not expected. Other injuries from the direct effects of blast overpressure are unlikely, although there are likely to be injuries from secondary effects, i.e. the ejection of objects;
- buildings which are unstrengthened can be expected to suffer damage to main structural members;
- cars may suffer some damage to metal parts of the body and roof by blast. Windows facing the blast may be broken; however, the glass should not cause serious injuries to the occupants;
- aircraft will suffer some damage to appendages and sheet metal skin. They should be operational with only minor repair.

The AASTP-1 states that the $9.6Q^{1/3}$ Q-D function should normally be the minimum distance at which unprotected duty personnel should be permitted when their duties are not closely and specifically related to the PES.

Projection criterion

Projection hazards are hard to predict and cannot be related to scaled distances, because the fragmentation process involves varying degrees of randomness in the break-up of the metal case surrounding the bursting charge and the structural material of the explosion site. The real projection hazard depends on the type of ammunition and the type of storage facility and the level of protection the surrounding barricades offer. However, there is likely to be a hazard from projections at all scaled distances less than $14.8Q^{1/3}$, and this hazard will be greater when the PES is not barricaded (NATO AASTP-1).

The generally accepted hazard criterion for unprotected personnel is one hazardous fragment (with minimal kinetic energy of 79 J) per 56 m^2. Because of the abovementioned difficulties, this criterion cannot be translated in Q-Ds for specific ammunition/storage facility combinations, unless these combinations are thoroughly evaluated on fragmentation.

A more practical approach on the quantification of projection hazards is given in the NATO AASTP-1 manual. The manual presents the following projection hazards for 'all types of PES's' as a function of distance for NEQs in excess of 4500 kg.

D=180 m
There is a significant hazard from projections at 180 metres. This hazard is tolerable for:

- public traffic routes when the traffic is not heavy and when the PES is an open stack or a light structure;
- unbarricaded ammunition to prevent propagation from low trajectory, high velocity projections.

D=270 m
There is a significant hazard from projections at 270 metres. The hazard is tolerable for:

- main public traffic routes or when the traffic is heavy and when the PES is an open stack or light structure;
- public traffic routes when the traffic is not heavy and when the PES is a heavy-walled or earth-covered building;
- sparsely populated areas when the PES is an open stack or a light structure; there would be a small expectation of damage or injury from projections.

D=400 m
There is a minor hazard from projections. This hazard is tolerable for:

- main public traffic routes or when the traffic is heavy and when the PES is a heavy-walled or earth-covered building;
- built-up areas when the PES is an open stack or a light structure;
- all inhabited buildings when the PES is a heavy-walled or earth-covered building.

The fragmentation hazard corresponding with an ES distance of 180 m is adopted by the RNLA and RNLAF. The hazard is determined for NEQs in excess of 4500 kg. Although projection hazards are not a consistent function of NEQ, it is expected that the projection hazards are less severe when one storage module, only containing an NEQ between 500 kg and 5000 kg, explodes.

The blast criterion (Equation 1) and the minimum distance of 180 metres is graphically presented in Figure 1 for a wide range of NEQs.

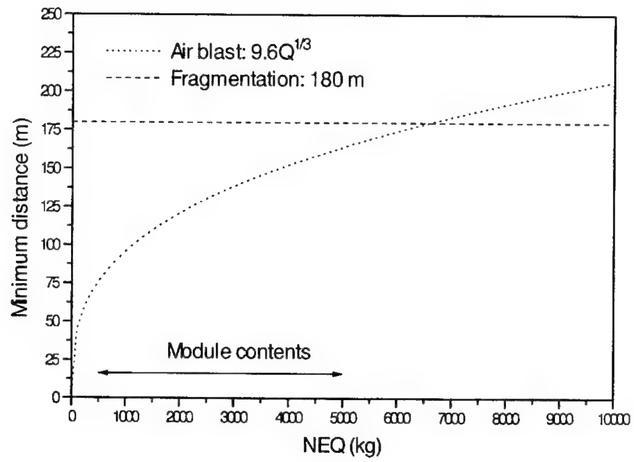

Figure 1: Q-D functions for the defined accepted level of risk.

In the case of the modular storage concept, in which one storage module contains an NEQ in the range of 500 to 5000 kg, the criterion on fragmentation overrides that on air blast. In other words, for net explosive quantities less than 6600 kg, fragmentation forms the major hazard. Therefore, it would be sensible to give priority to measures to reduce the projection hazard in future developments of field storage facilities.

3.2 Case definition

To evaluate current standards, which include regulations on non-permanent field storage of ammunition and explosives, on aspects like explosion safety, operational flexibility, guideline flexibility, etc., a fictitious case is defined. This case is defined on the basis of the specific demands of the RNLA and RNLAF as discussed in the previous section. This case includes the design of a storage site for twenty TEU-containers filled with four types of (RNLA) ammunition and explosives. All basic information about the contents of these containers is presented in Tables 2 and 3.

Table 2: Container contents.

Container type and number	A 10	B 5	C 2	D 1
Ammunition	5.56 mm	155 mm	DRAGON	Demol. kit
HD	1.4S	1.1D	1.1E	1.1D
Amount	375 boxes	15 containers	15 boxes	100
Volume (m^3)	9.9	7.8	22.6	12.6
Gross weight (kg)	7500	7100	6000	5950
NEQ (kg)	1388	330	675	4200

Table 3: Weights of ammunition and explosives as a function of Hazard Division.

	HD1.1	HD1.4
Total gross weight (kg)	53450	75000
Total NEQ (kg)	7200	13880
NEQ/Gross weight-ratio (%)	14	19

The modular storage concept is observed in which the containers are positioned in rows beside a main supply road. To evaluate the standards, a number of basic questions are formulated. Questions resulting in quantitative answers are:

1 What are the minimum interior and exterior Q-Ds?
2 What are the explosion effects and level of damage when a mass explosion in one container occurs?

Questions for qualitative considerations:

1 Are the regulations consistent?
2 Are the regulations user-friendly?
3 What are the recommendations on storage facilities concerning weather protection/security/selection of sites/etc.?

The main standards, which include regulations on field storage of ammunition and explosives, are consulted and evaluated on the above-mentioned aspects. The results of this study are summarized in the next chapter. The NATO AASTP-1 manual is taken as reference for the quantification of the explosion effects as a function of the NEQ and recommended Exposed Site distance.

4 Present standards and evaluation

There are a number of standards in which guidelines for safe storage of ammunition and explosives are presented. Only a few of them include regulations on field storage for use in missions out of area. These standards, made available to TNO-PML[2], are:
1 NATO AASTP-1;
2 UN Logistics Directives: Log Dir 100, 101 and 312;
3 Standards: DoD 6055.9-STD, TM 9-1300-206 and DAP 385-64;
4 Norwegian field regulations 16-5-2 and 16-5-4.

In this chapter, the information of interest is summarized and evaluated for the case as defined in the previous chapter (Section 3.2).

4.1 NATO AASTP-1

The forerunner of the NATO AASTP-1 manual was originally established by four NATO members (France, Germany, United Kingdom and the United States of America) in 1963. Later on, also other NATO members participated in the 'group of experts on safety aspects of transportation and storage of military ammunition and explosives AC/258'.
The primary object of the manual is: 'to establish safety principles to be used as a guide between host countries and NATO forces in the development of mutually agreeable regulations for the layout of ammunition storage depots and for the storage of conventional ammunition and explosives therein'. These principles are intended to form the basis of national regulations as far as possible. The manual is intended to serve as a guide for authorities who are engaged in the planning and construction of ammunition storage depots of a capacity of *not less than 500 kg NEQ per storage site* and for those who are responsible for the safe storage of ammunition. As stated in the manual, the risk included in the recommendations, represents an acceptable compromise between absolute safety and practical considerations of cost or operational requirements.

Parts I to III of the AASTP-1 manual prescribe quantity-distances for all kinds of permanent storage facilities during peacetime. The international system of classification devised by the UNO is dealt with. The definitions of hazard classifications and compatibility groups are presented as well as the levels of protection (Q-D functions) and corresponding expected levels of damage. Also, the expected projection hazards for three basic distances (180, 270 and 400 metres) are given (see also Chapter 3 on 'accepted risk').

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[2] TNO-PML is grateful to U.S. and NO Key Delegates for sending their national regulations on field storage.

In 1981, it was decided to publish a new part (part IV) dealing with quantity-distance criteria for airfields. For those situations it was not possible, without seriously prejudicing operational effectiveness, to apply the standard principles. From that date on, the regulations on field storage, missile installations and basic load ammunition holding areas were also published in this part of the manual.
It is obvious that in those cases standard guidelines cannot be complied; a reduced level of protection has to be accepted. In the AASTP-1, it is stated that the decision whether to use the explosion safety principles contained in parts I to III or to use those in parts IV has to be made by National Authorities. Consequences of a reduced level of protection are well-documented within the AASTP-1.

Part IV of the AASTP-1 is divided into six chapters. Three chapters are of major interest to this study. These are:
1 Field storage (including general Q-D principles);
2 Q-D principles for basic load ammunition holding areas (BLAHAs);
3 Q-D principles for airfields used only by military airfields.

The scopes and basic differences between these chapters of Part IV are discussed in the next sections. Each section ends with an evaluation of the case defined in Section 3.2.
In order to quantify the different approach on accepted risk, the regulations for permanent storage in peacetime are summarized first in the following.

4.1.1 Permanent storage in peacetime

The aboveground storage of ammunition and explosives in permanent depots are well-considered in part I of the AASTP-1 manual. Protection levels for air blast are quantified with Q-D functions. The minimum distance required is determined by the hazard of fragments.
The prescribed net quantity-distances include corresponding explosion effects and damage levels to be expected. Some Q-D functions relevant to this study, the corresponding expected blast effects and their applications are presented in Table 4. Projection hazards and related damage levels are described separately (see Chapter 3 on 'accepted risk' for detailed information).

Table 4: Protection levels for open stacks and light structures with HD1.1 ammunition (Q>500 kg NEQ).

Q-D function, (Q in kg and D in metres)	Expected blast peak incident overpressure (kPa)	Application
$D^* = 44.4Q^{1/3}$ to $33.3Q^{1/3}$	2 to 3	Vulnerable constructions
$D_{13} = 22.2Q^{1/3}$ for $Q \geq 4500$ $D_{13} = 5.5Q^{1/2}$ for $Q<4500$	5	IBD
$D_{11} = 14.8Q^{1/3}$ for $Q \geq 4500$ $D_{11} = 3.6Q^{1/2}$ for $Q<4500$	9	PTRD
$D^* = 9.6Q^{1/3}$	16	Blast criterion of RNLA and RNLAF
$D^* = 7.2Q^{1/3}$	24	Explosives workshop separation (used by US)

* Not implemented in Q-D tables for HD1.1 ammunition.

Evaluation with case study
In the fictitious situation that a storage site has to be designed for the twenty containers as defined in Table 2, the following recommendations are given by part I of the AASTP-1 manual.

The total gross weight and NEQ of ammunition and explosives of HD1.1 is 53450 kg and 7200 kg, respectively. The total gross weight and NEQ of the HD1.4 ammunition are 75000 kg and 3300 kg, respectively (Table 3). However, according to the mixing rules (annex C of part I), HD1.4 may be stored with any other HD without aggregation. Also, it is permitted to mix compatibility group (CG) 'D' with CG 'E'. These regulations mean that only HD1.1 with a total NEQ of 7200 kg has to be considered. If the containers are defined as open-air stacks or light structures, the interior and exterior distances presented in Tables 5 and 6 have to be considered (AASTP-1, Table 1, page I-A-13).

Table 5: Interior distances for permanent storage.

Interior distances between containers:	Without barricades D_9 (m)	With barricades D1 (m)
B-B	39	3
C-C	43	4
B-C	83	6
C-D	83	6

Table 6: Exterior distances for permanent storage.

Exterior distances	Without barricades (m)	With barricades (m)
IBD (D13)	445	445
PTRD (D11)	300	300

The interior distances are reduced by a factor greater than 10, when proper barricades are applied. The exterior distances are not affected by the use of barricades, because barricades are ineffective in reducing blast pressure in the far-field area.

4.1.2 Field storage in general

The first chapter of part IV of the AASTP-1 manual presents directives to set-up relatively large field areas for storage of ammunition and explosives up to 5000 tons gross weight in the theatre of operations, that is, in the communications zone and the combat zone. The principles for field storage are based on units of quantities.
The smallest unit or module defined is a *field_stack_module*. Examples of such modules are a loaded vehicle or a container. The maximum quantity stored must not exceed 10 tons gross weight.
With field stack modules, a *field storage site* can be formed containing a maximum of 200 tons gross weight of ammunition and explosives. If the ammunition contains more than 50% NEQ of the gross weight, then the gross weight should be limited to 40 tons maximum.
The positioning of modules in a field storage site is rather strict and based on explosion safety principles (i.e. to prevent sympathic detonation) and rapid access to the articles stored. The minimum length of a row of 10 modules is 50 metres. In the case of TEU containers, the distance between them is about 1 to 2 metres. The AASTP-1 states that, if possible, a distance of at least 25 metres between modules should be observed as a fire break. Of course, this will increase the size of a field storage site considerably, which may not be desirable for security or operational reasons.

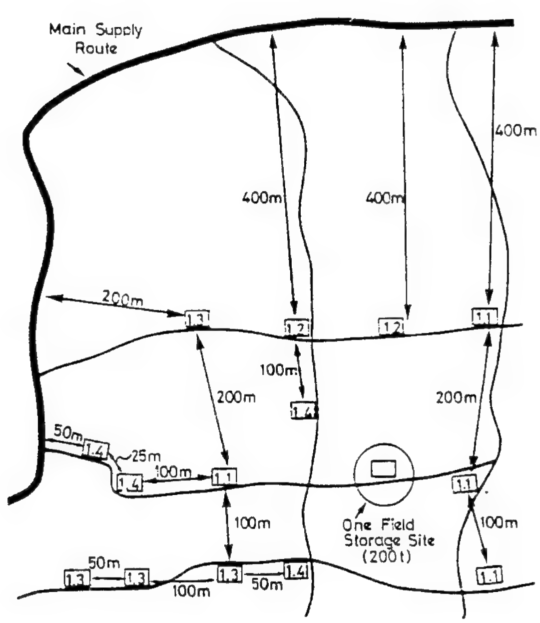

Figure 2: Typical field storage area (Figure 2-III, AASTP-1).

In the case of storage of more than 200 tons of ammunition and explosives, *a field storage area is* defined containing a maximum of 5000 tons gross weight. Such an area is based on a maximum of 25 field storage sites. An example of an entire field storage area is shown in Figure 2.
The interior and exterior quantity distances are based on explosion safety principles for the separate field storage sites, thus a maximum of 200 tons *gross* weight.

The manual describes special conditions for small holding areas (600 tons gross weight instead of 2000 tons). The corresponding field storage sites should contain a maximum of 50 tons gross weight. The related interior and exterior distances are presented in Tables 7 and 8. The Q-Ds of the 50 tons storage sites are given between brackets.

Table 7: Minimum interior Quantity-Distances for field storage sites of 200 tons and 50 tons (50 tons between brackets), AASTP-1, Table 2-I and 2-III.

HD	1.1	1.2	1.3	1.4 [a]
1.1	200 (100)	100	100	100
1.2	100	100	100	100
1.3	100	100	50	50
1.4 [a]	100	100	50	25

a Ammunition of Hazard Division 1.4S may be stored without regard to distances.

Table 8: Minimum exterior Quantity-Distances for field storage sites of 200 tons and 50 tons (50 tons between brackets), AASTP-1, Table 2-II and 2-IV.

ES	HD of ammunition at PES	Minimum distance (m)
Main supply routes	1.1	400 (250)
	1.2	400 (200)
	1.3	200 (100)
	1.4	50
Inhabited buildings, barracks, etc.	1.1	500 (400)
	1.2	500 (300)
	1.3	300 (200)
	1.4	50
Hospitals, stations, airfields, other military storage depots, radio sites	1.1	1000
	1.2	1000
	1.3	500
	1.4	50

Table 7 shows that the difference in minimum interior distances for storage of 50 tons or 200 tons is small (only the minimum interior distance of HD1.1 ammunition is affected).

The advantages of this modular storage concept are that it is very straightforward and therefore easy to apply by the Field Commander. However, there are two basic disadvantages:

1 The Q-Ds are based on gross weights instead of NEQs, which determine the level of risk. The NEQ/gross weight-ratio depends very much on the type of ammunition (i.e. 5% for 155 mm HD1.1 grenades and 46% for Mk 84 GP '2000 lbs' bombs). This will lead to situations in which the Q-Ds are rather conservative or just critical. In other words, the level of risk becomes variable and not known, which is not desirable for Field Commanders.

2 Q-Ds are only prescribed for two maximum gross weights of ammunition (50 tons and 200 tons). Q-Ds are not presented as variable functions. Again, this will lead to variable levels of risk.

Besides the presentation of regulations regarding the separation of hazard divisions and segregation of different compatibility groups, the chapter on field storage in general presents also remarks on:
- the selection of sites (4.2.1.8.);
- layout of sites (4.2.2.6.);
- building of stack modules (4.2.2.7.);
- provision of protection against the weather (4.2.2.8.);
- fire-fighting (4.2.3.1 and 4.2.3.2.).

Evaluation with case study
A storage location is designed to store the twenty containers with ammunition and explosives as described in Table 2. The total gross weight of ammunition and explosives of HD1.1 is about 53.5 tons. Their total NEQ/gross weight-ratio is about 17% and is well below the 50% limit. According to Part IV of the manual, HD1.4 ammunition may be stored on any unoccupied portion of the site. Secondly, because HD1.4S ammunition presents no significant hazard, it may be stored without regard to distances. As a result, the total amount of ammunition is limited to 53.5 tons gross weight.
If taken literally, exterior distances based on a storage site with a maximum of 200 tons gross weight should be considered, since 53.5 tons exceeds the 50 tons limit. The decision to be taken shows exactly the disadvantage of the given guidelines. For this case, the exterior distances based on a storage site of 50 tons gross weight of HD1.1 are taken (see Table 9).

Table 9: Exterior distances based on storage site of maximum 50 tons gross weight.

Description of Esposed Sites	Exterior distance (m)
Main supply routes	250
IB, barracks	400
Hospitals, stations, airfields, other military storage depots, radio sites	1000

The containers should be separated by at least 1 to 2 metres. If possible, a distance of at least 25 m between the containers should be observed as a fire break. It is expected that this latter advice is hard to follow, since it requires a larger storage site and better security.

If the prescribed exterior distances are compared with those for permanent storage in peacetime (i.e. IBD = 445 m), it can be concluded that the risk level in the case of field storage is not increased as much as expected. This conclusion applies also for the interior distances, especially when the 25 m restriction for field storage is observed. Since the accepted level of explosion effects and damage to the environment is not quantified in Part IV regarding field storage, and because of the explained disadvantages, the recommendations in this chapter of Part IV of the manual are less suitable for Field Commanders.

4.1.3 Q-D principles for BLAHAs

Beside the standard regulations for relatively large field storage sites and areas, the manual presents quantity-distance principles for Basic Load Ammunition Holding Areas (BLAHA). The AASTP-1 states that these principles are designed for combat units, which have to keep their basic load ammunition in readiness within the boundaries of their barracks or in the immediate vicinity thereof. Interior quantity-distances are smaller to allow units to fulfil their mission. As a result, a higher level of risk to military personnel and material is accepted. The exterior distances (like IBD, PTRD) are not reduced.

Another basic difference with the regulations for common field storage is that the interior and exterior distances are functions of the NEQ of ammunition and explosives. The disadvantages of the general field storage regulations are therefore cancelled.

The regular Q-D tables are concerned with storage sites *containing more than 500 kg NEQ*. For BLAHAs, distances are specified in an NEQ range from 50 kg to 4000 kg. The manual defined 6 BD-functions, the descriptions of which are presented in Table 10.
Only the storage of HD1.1 and HD1.2 is considered in this section, in which HD1.2 is regarded as HD1.1. All components necessary for complete rounds of artillery, mortar and rocket ammunition may be stored together without accounting for compatibility. The maximum NEQ at any site in a BLAHA must not exceed 4000 kg.

Table 10: Application of BD-functions for BLAHAs.

BD-function	Application
BD1 = $0.8Q^{1/3}$	Interior distance from trucks and trailers when barricaded
BD2 = $1.8Q^{1/3}$	Interior distance from earth-covered structures in end-to-end configuration and when barricaded
BD3 = $4.8Q^{1/3}$	Interior distance for trucks and trailers when unbarricaded
BD4 = $3.6Q^{1/2}$	PTRD from vehicles with light armour
BD5 = $5.5Q^{1/2}$	IBD from vehicles with light armour. Barracks, headquarters and maintenance facilities from trucks and trailers.
BD6 = $1.5Q^{2/3}$	IBD and PTRD from vehicles with heavy armour

Evaluation with case study

Because the maximum NEQ for one storage site may not exceed 4000 kg, two sites have to be set up. In this case, the first site is only one container of type D, which is filled with an NEQ of 4200 kg of HD1.1 demolition kits. The second site contains five containers of type B and two containers of type C, both of HD1.1. The recommended minimum exterior and interior distances for both sites are presented in Tables 11, 12 and 13.

Table 11: ***Exterior** distances for **storage site 1** (one container of type D with total NEQ of 4200 kg).*

Description of Exposed Sites	Distance (m)
Inhabited buildings	360
Barracks, headquarters and maintenance facilities	360
Public traffic routes	235

Table 12: ***Interior** distances for **storage site 2** (seven containers of type B and C with total NEQ of 3000 kg).*

Interior distances between containers:	Distance when unbarricaded (m)	Distance when barricaded (m)
B-B	34	6
C-C	43	8
B-C	43	8

Table 13: ***Exterior** distances for **storage site 2** (seven containers of type B and C with total NEQ of 3000 kg).*

Description of Exposed Sites	Distance (m)
Inhabited buildings	305
Barracks, headquarters and maintenance facilities	305
Public traffic routes	205

There are no recommendations given for the minimum distance between the two storage sites. When BD1 (barricaded) and BD3 (unbarricaded) are observed, the distances are 13 and 78 m, respectively.

In the introduction of this chapter of Part IV, it was stated that a higher level of risk was accepted in relation to interior quantity-distances. When the minimum interior distances recommended for BLAHAs are compared with those recommended for permanent storage in peacetime (Table 5), this is not the case. Moreover, in the case of barricaded containers, the interior distances for BLAHAs are even greater than those for permanent storage in peacetime.

In general, it is concluded that the NATO AASTP-1 manual contains all the information of interest for permanent storage of ammunitions and explosives in peace-

time. The disadvantage is that the accessibility of the information is very poor. The regulations on field storage do not give detailed information on the accepted levels of risk. In spite of the inconsistency regarding the accepted level of risk, the safety principles for basic load ammunition holding areas are applicable for the RNLA and RNLAF.

4.2 UN Logistics Directives

Military units operating under the flag of the UN use Logistics Directives for all kinds of military activities, including ammunition and explosives storage. To TNO-PML, it is not very clear by whom these directives are accomplished and what the references of these directives are.
In this study, the following Logistics Directives, used by UNPROFOR and UNTAC units, are discussed and evaluated:
- UNPROFOR Log Dir 312, Ammunition and explosives;
- UNTAC Log Dir 101, Ammunition and weapons recovery plan;
- UNTAC Log Dir 100, Ammunition and explosives.

4.2.1 Logistics Directive 312 (UNPROFOR)
The UNPROFOR Logistics Directive 312 presents regulations for storage in the field during UNPROFOR missions. There are several versions of this directive published. TNO-PML has two versions; one dated May 1992 (no version number) and one dated 20 March 1993 (Version 2.2).

4.2.1.1 Log Dir 312 (dated May 1992)
In the Logistics Directive 312 (dated May 1992), the potential explosive site is subdivided into two hazard divisions:
- PESs with small arms ammunition (SAA) and pyrotechnics with a maximum weight of 50 tons;
- PESs with high explosives (HE) with a maximum weight of 10 tons.

The basic information whether the maximum weights are gross weights or net weights is not given in the directive. It is assumed that NEQs are meant. Furthermore, it is not explained what the definition of pyrotechnics is.

The prescribed distances for *SAA and pyrotechnics* storage areas are respectively:
- 50 metres from any inhabited buildings, main road;
- 100 metres from any sleeping accommodation or POL installation;
- 25 metres from any other ammunition and explosives storage area.

The prescribed distances for *HE* storage areas are respectively:
- 400 metres from any inhabited buildings, sleeping accommodation, main road;
- if possible, 1000 metres from airfields, POL installation, hospital and overhead electric power lines;
- 100 metres from any other HE area.

Evaluation with case study
The ten containers of type A filled with SAA of HD1.4S have an NEQ of 13880 kg. This NEQ is lower than the prescribed maximum of 50 tons, so the guidelines as valid for SAA have to be observed for these ten containers.
The other ten containers are filled with an NEQ of 7200 kg of HD1.1. It is assumed that the 155 mm grenades and the DRAGON anti-tank missiles can be described as HE. In that case, the distances as presented for HE storage areas have to be observed.

4.2.1.2 Logistics Directive 312 (Version 2.2, dated 20 March 1993)
The Logistics Directive does not prescribe a maximum weight of ammunition to be stored in a storage site. The lack of such vital information is remarkable. If the same maxima are assumed as prescribed in the directive dated May 1992 (maximum NEQ of 10 tons for HE, and maximum NEQ of 50 tons for SAA and pyrotechnics), the following distances are imposed.

The prescribed distances for *SAA and pyrotechnics* storage areas are respectively:
- 25 metres from any inhabited buildings;
- 100 metres from any sleeping accommodation or POL installation;

The prescribed distances for *HE* storage areas are respectively:
- 150 metres from any inhabited buildings, sleeping accommodation or POL installation;
- remote from airfields, pipelines and overhead electric power lines.

Evaluation with case study
The same storage concept as applied to the earlier version can be observed. However, there are a number of basic differences concerning the imposed distances:
1 the distance to vulnerable ES's was originally 400 metres, and was decreased to 150 metres in the later Version 2.2. The reason for this reduction is not given;
2 the latest version presents a further lack of information. Version 2.2 does not prescribe any maximum weight of ammunition or explosive that may be stored;
3 the definition of a 'remote' distance is not applicable for a Field Commander.

As mentioned in point 1, the IBD was reduced from 400 m to 150 m for a maximum NEQ of 10 tons HE. This Q-D corresponds to the Q-D function $D=7.0Q^{1/3}$. The NATO AASDTP-1 manual described the expected blast effects for the protection level $D=7.2Q^{1/3}$, of which the most important ones are (AASTP-1, page I-4-48):
- damage of unstrengthened buildings will be of a serious nature. Repair is likely to cost 50% or more of the total replacement cost;

- personnel injuries of a serious nature or possible death are likely from debris of the building at the ES and from of loose objects;
- there is a 1% chance of eardrum damage to personnel.

Within a radius of 150 metres, the hazard from projections is expected to be even greater. It is obvious that this level of damage is not acceptable to the RNLA and RNLAF.

Summarized, the following remarks are given for both versions of the Logistics Directive 312:
- the general HD system of NATO and UNO is not used. The ammunition and explosives are only subdivided into 'SAA and pyrotechnics' and 'high explosives'. The definition of 'pyrotechnics' is not given;
- the directives do not give information whether net or gross weights of ammunition and explosives are prescribed;
- although essential in explosion safety terms, the term 'minimum distance' is not mentioned in either version of the directive;
- the accepted risk is significantly higher than defined in the NATO AASTP-1 manual for field storage out of area.

4.2.2 Logistics Directive 101 (UNTAC)

The Logistics Directive 101 'Ammunition and weapons recovery plan' (dated 5 September 1992) describes the procedures to be employed for the recovery of ammunition, weapons and equipment during and after the cantonment phase of the UNTAC mission.

In Section 4.5 of this directive, in which 'cantonment site procedures' are given, it is stated that recovered ammunition should be stored in a secure area at least *150 metres from inhabited sites*. The ammunition should be segregated by type. The Logistics Directive 100 was given as a reference for this distance. Maximum net or gross weights related with this distance are not presented.

Annex G of the directive deals with the storage of ammunition. This section describes criteria for the selection of storage sites and is almost similar to the criteria of the AASTP-1 manual. Also, the terms stack module, storage site and storage area including maximum gross weights of respectively 10 tons, 200 tons and 5000 tons are copied. The minimum interior and exterior distances prescribed are:

1 'The distance between stack modules should ideally be 25 metres. Security and operational considerations should be taken into account when considering reduction of the 25-metres distance.'

2 'The distance between storage sites (20 stack modules) should be 100 metres, except that sites containing ammunition with a mass explosion hazard (mines, bulk explosives, etc.) must be separated by 20 metres and sites containing small arms ammunition only may be separated from similar sites by 25 metres.'

3 'Storage areas shall be separated from other storage areas by at least 1000 metres.'
4 'Administration areas shall be at least 200 metres from ammunition.'

However, the exception in the second recommendation is remarkable. The nominal distance between storage sites (maximum 200 tons gross weight) should be 100 metres, but sites with ammunition of HD 1.1 should be separated by 20 metres. This is rather inconsistent. It is assumed that 200 metres is meant and that 20 metres is a typing error. In that case, the prescribed distances of points 1, 2 and 3 are exactly the same as stated in the NATO AASTP-1 manual. The reference of point 4 is not given.

Annex H of this directive prescribes disposal procedures and safety precautions. In this annex it is stated that the disposal area shall be located with a minimum safety distance of *730 metres* between the actual disposal point and *surrounding magazines, explosives workshops and inhabited buildings, places of assembly, highways and railroads*. The reference of this distance is not given and not found out.

The construction of barricades to prevent explosion propagation from one stack of ammunition to another is mentioned. However, detailed information about barricades or examples are not given.

4.2.3 Logistics Directive 100 (UNTAC)

The aim of Logistics Directive 100 'Ammunition and explosives' (dated June 1992) is to outline the procedures to be followed by units in demanding, storing, inspecting and disposing of ammunition and explosives. Annex B presents the storage regulations for ammunition and explosives.
Exactly the same regulations as prescribed in Log Dir 312 Version 2.2 (dated 20 March 1993) are presented, including the same lack of information (i.e. maximum allowed net or gross weights of ammunition and explosives in storage site). Therefore, the same conclusions as drawn for Log Dir 312, Version 2.2, apply to the Log Dir 100.

The following general conclusions can be drawn regarding Logistics Directives 100 and 101:

- the prescribed distances are inconsistent. Directive 101 advises a distance of 150 metres to inhabited buildings, and refers to Directive 100. In the annex of Directive 101, Q-Ds are based on the AASTP-1 manual. However, the distances are copied incorrectly;
- directive 100 presents a summary of the insufficient guidelines of Directive 312, Version 2.2.

4.3 U.S. Standards

The American Department of Defence Explosives Safety Board (DDESB) established safety standards for ammunition and explosives. In 1983, the first edition of the DoD 6055.9-STD standard was published, which applies to all DoD components, such as the Military Departments, the Unified and Specified Commands and the Defence Agencies. These general safety standards were implemented in the technical (U.S. Army) manual TM 9-1300-206 'Ammunition and explosives standards' and the Army Regulation AR 385-64 'U.S. Army explosives safety program' which includes the Department of the Army Pamphlet DAP 385-64 'Ammunition and explosives standards'.

The TM 9-1300-206 was a technical manual for the field troops of the U.S. Army that implemented DoD quantity-distance criteria and included much additional information on general safety for explosives areas, field storage, ammunition surveillance and quality assurance, etc., up until about 1990. The document is no longer officially used. However, it is of value since it gives some good advice on field storage that is not covered in other documents at this time.
The Department of the Army Pamphlet DAP 385-64 is the current military publication that explains the U.S. Army's safety criteria and standards for operations involving ammunition and explosives.

Because the U.S. Air Force uses different types of ammunition and storage facilities, they established their own manual on explosives safety. The U.S. Air Force Manual AFM 91-201 'Explosives safety standards' implements Air Force Policy Directive AFPD 91-2 'Safety programs' and aligns with DoD 6055.9-STD. Because the manual does not include specific information on field storage in case an improvised airbase has to be set up, it is not discussed in this report.

4.3.1 U.S. DoD 6055.9-STD

This standard starts with an introduction of the effects of explosions and permissible exposures. It handles the hazard classification and compatibility groups of ammunition and explosives as devised by the UNO and it presents quantity-distances for both permanent storage in the interior zone (=U.S.A.) and non-permanent storage in the theatre of operations.

Permanent storage in the interior zone (=U.S.A.)
The definitions of the levels of protection (Q-D functions) for *air blast* are slightly different to those defined by the NATO AASTP-1 (see Table 4). An important difference with AASTP-1 is that the DoD include small NEW (net explosive weight in pounds) from 1 lb up to 500.000 lbs. The AASTP-1 manual starts with a minimum NEQ of 500 kg. Some of the protection levels the DoD handles are presented in Table 14.

Table 14: Protection levels for open stacks and light structures with HD1.1 ammunition (Q>0.5 kg NEQ).

Q-D function (SI-units)	Overpressure (kPa)*	Application
$16Q^{1/3}$ to $20Q^{1/3}$	8.3 to 6.2	IBD
$9.6Q^{1/3}$ for Q<50000 kg	16	PTRD
$12Q^{1/3}$ for Q>125000 kg#	12	
$7.2Q^{1/3}$	24	Unbarricaded intraline distance
$4.4Q^{1/3}$	55	Unbarricaded aboveground magazine distance
$3.6Q^{1/3}$	83	Barricaded intraline distance
$2.4Q^{1/3}$	186	Barricaded aboveground magazine distance

* Expected blast peak incident (side-on) overpressure (kPa).

\# A function for NEQs between 50.000 kg and 125.000 kg is not given.

Table 14 shows that the accepted blast effects for inhabited buildings as well as public traffic routes are higher than accepted in the AASTP-1 manual.

The American DoD standard includes required minimum *fragment* distances as a function of NEQ of ammunitions and their hazard divisions. AASTP-1 only gives levels of damage due to fragments for four basic distances. The minimum fragment distances are to protect personnel in the open. For densely populated locations, the minimum distance shall be that distance at which fragments, including debris from structural elements of the facility, shall not exceed a hazardous fragment density of one fragment per 56 m^2. This accepted risk is the same as stated in the AASTP-1 manual. In case this distance is not known, the minimum distances as presented in Table 15 have to be observed.

Table 15: Minimum fragment distances.

Ammunition weight and HD	Minimum required distance (m)
< 45 kg NEQ of HD1.1	204
46 kg to 13600 kg NEQ of HD1.1	380

For a selected number of HD1.1 ammunition, which have been evaluated adequately, different minimum distances are given (see Table 16).

Table 16: Minimum fragment protection distance for selected HD1.1 ammunition (summary of Table 9-2, DoD 6055.9-STD).

Type of Ammunition	Distance required (m) 1 Unit	2 Units	5 Units	10 Units
Bomb, 500 lb, Mk82	204	262	329	378
Projectile, 155 mm, M107	122	156	220	454
Projectile, 105 mm, MI	82	107	153	305
AIM 9	122	122	122	122

As for all explosive safety standards, the required minimum distances for fragment hazards override the Q-D functions for air blast.

Semi-permanent storage in the theatre of operations
Chapter 10 of the DoD 6055.9-STD prescribes quantity-distances in the theatre of operations. The contents of this chapter are basically the same as the chapters on BLAHAs and airfields of the NATO AASTP-1 manual. However, a chapter on general field storage regulations (like AASTP-1, Part IV, Chapter 2) is not included.
The Q-D table for BLAHAs as presented in the DoD standard (Table 10-1) contains some major errors. The D4 and D5 functions are written as $3.6Q^{1/3}$ and $5.5Q^{1/3}$, respectively, while they should be $3.6Q^{1/2}$ and $5.5Q^{1/2}$. The BD6 function is not included at all.

In the general introduction of BLAHAs, it is stated that the accepted risk to unit personnel, facilities and equipment is greater than for normal peacetime conditions. For BLAHAs, the minimal fragment requirements, as mentioned for peacetime permanent storage, apply only for exposures involving non-military personnel, family housing, health and morale facilities.

Evaluation with case study
See evaluation of NATO AASTP-1 manual, Part IV, section on BLAHAs.

4.3.2 U.S. DAP 385-64

As mentioned in the introduction to the American standards, the Department of the Army Pamphlet DAP 385-64 is the current military publication that explains the U.S. Army's safety criteria and standards for operations involving ammunition and explosives. Because the pamphlet is an implementation of the DoD 6055.9-STD standard, much of the numbers are identical. However, the pamphlet is a more practical handbook to be used by the military in the field. Separate chapters for peacetime overseas operations and wartime operations are included.

Storage for peacetime operations overseas
For peacetime operations overseas, the quantity-distance table for basic load holding areas (BLAHAs) is the same as prescribed in the American DoD 6055.9-STD standard and the NATO AASTP-1. Unlike the typing errors in the DoD standard, the numbers in the DAP are correct.

Storage for wartime operations overseas
For wartime and contingency operations, (qualitative) options are provided to the commander faced with various and changing battlefield hazards, based on the acceptance of ever increasing degrees of risk. The pamphlet gives several fundamental concepts which govern the relaxation of peacetime explosives safety stan-

dards during combat and contingency operations and the acceptance of added risks. The main concepts are:

- where Q-D considerations must be relaxed, prevention of propagation and the preservation of military equipment, personnel, and ammunition should be paramount;
- the third (unwritten) factor in Q-D explosives safety calculations is time. The degree to which standards are relaxed should be directly related to the duration of the exposure. Relaxation of standards for 24 hours involves less risk than relaxation for 48 hours;
- the acceptance of a high degree of explosion risk is dependent upon the competing hazards of the battlefield. The risk of an accidental explosion is higher as ammunition approaches the 'Forward Line Of Troops' (FLOT);
- ammunition logistical considerations and warfighting requirements should take precedence over compatibility in the mixing and grouping of ammunition items;
- HD1.2 ammunition should be treated as HD1.1. When it becomes impractical to manage ammunition by HD, all ammunition, except identifiable HD1.4, should be treated as HD1.1. All captured ammunition, mixed ammunition, and unserviceable/unknown ammunition will be treated as HD1.1.

Regarding Q-Ds, as far as the local situation allows, the peacetime Q-Ds should be observed. The pamphlet states that, where the local situation does not allow for this level of external protection, the internal protection should be maintained.

Evaluation with case study
See evaluation of NATO AASTP-1 manual, Part IV, section on BLAHAs.

4.3.3 U.S. TM 9-1300-206

As mentioned in the introduction to the American explosives safety standards, the TM 9-1300-206 was a technical manual for the field troops of the U.S. Army. Although the manual is no longer in use, it includes some alternative approaches in field storage.

A separate section is devoted to the storage of ammunition and explosives in the Theatre of Operations (TO). It is stated that storage in the TO should follow the standards outlined for the zone of interior (=U.S.A.), except for the combat zone configuration. However, the concerning section on storage in combat zones states, 'Normal explosives safety criteria, procedures, Q-D separations and methods of applications apply in the usual manner except where waivers are granted'. These statements are conflicting, which is further underlined by the definition of specific field storage categories for use in the TO. The rest of the manual uses the generally accepted UNO Hazard Division classification system.

The manual states, 'Field storage categories are the primary groups into which ammunition is segregated for temporary storage in the field. The groupings are based on consideration of the desirability of storing components of complete

rounds in adjacent stacks and on consideration of the hazards of propagating of explosion, range of fragments, spread of fires and chemical contamination'. The categories for storage of conventional ammunition are:

Category A
Fixed and semi-fixed artillery ammunition, except incendiary and chemical.

Category B
Propelling charges, fuses, primers, flash reducers and separate loading artillery projectiles including HE and AP, but excluding incendiary and chemical projectiles.

Category C
Mortar ammunition and hand-grenades, except incendiary and chemical.

Category D
Pyrotechnics and chemical ammunition of all types, including chemical-filled rockets; gas, smoke, and incendiary bombs; gas and smoke artillery ammunition; incendiary and chemical grenades; smoke pots, VX-filled mines and bulk-packed incendiary and small-arms tracer cartridges.

Category E
All demolition explosives, anti-tank and anti-personnel mines (except VX-loaded) and components such as blasting caps, firing devices, detonating cord and safety fuse.

Category F
Rockets, rocket motors, guided missiles and rifle grenades, except chemical.

Category G
The following items of Air Force Class V supply: all unfused high explosive bombs, aircraft mines, aircraft torpedos and fragmentation bombs, fuses and/or primer-detonators for the above items and fragmentation bomb clusters, fused or unfused. The remainder of Air Force Class V items must be stored in other applicable categories.

Furthermore, the manual gives interior quantity-distances for storage categories C, E, F and G, based on gross weights. The interior Q-Ds for categories A, B and D are similar. Q-Ds for barricaded and unbarricaded stacks (less than 10 tons or 10 to 20 tons) and barricaded and unbarricaded Field Stack Units (FSU= two or more stacks) are presented (Table 4-4, TM 9-1300-206). Exterior Q-Ds are not presented for these specific field storage categories.

It is likely that the above-mentioned categories are introduced specifically for use in the field when it is not known what the hazard divisions and compatibility

groups of the ammunition and explosives are as defined by the UNO classification system.

Apart from the deviating definition of storage categories, the interior and exterior quantity distance regulations and hazard divisions as presented in the technical manual are similar to those in the DoD 6055.99-STD standard. An example of information which is not covered in the original DoD standard is given in Table 17. It presents the protection levels with the American Q-D functions, but includes also the estimated damage to structures and personnel.

The TM 9-1300-206 is a technical version of the DoD 6055.9-STD standard, which was used by field troops of the U.S. Army. Although the manual contains all the information of interest, the numbers and recommendations are not very accessible. The differences in policy on explosion safety principles for the different military operations (peacetime, theatre of operations, combat) are not clear.

Table 17: Probable effects of blast *overpressure (Table 5-0, TM9-1300-206).*

Overpressure (kPa)	Application	Q-D function	Damage*	Personnel
6.2 to 8.3	IBD	$15.9\text{-}19.8Q^{1/3}$	5-10%	Minor injuries may be caused by fragments or debris
12 to 16	PTRD	$9.5Q^{1/3}$	10-25%	Moderate to minor
24	Unbarricaded intraline	$7.1Q^{1/3}$	25-50%	Moderate to serious
55	Unbarricaded above ground	$4.4Q^{1/3}$	50-100%	Serious blast, fragments or debris, translation
83	Barricaded intraline	$3.6Q^{1/3}$	75-100%	Serious blast, fragments or debris, translation
186	Barricaded magazine distance	$2.4Q^{1/3}$	*Total*	*Major*, death by blast, debris, fragments

* Estimated damage to structures (the type of structure is not mentioned).

4.4 Norwegian field regulations

From the AC/258 Storage Subgroup, TNO-PML received a translation of the Norwegian national regulations on field storage of ammunition. It concerns some sections of the Army Logistics Field Regulations 16-5-2 and 16-5-4. They are based on the same classification system as used in the TM 9-1300-206. Field storage category G, which includes specific Air Force Class V items, is omitted. In contrast to the TM 9-1300-206, the Norwegian regulations include exterior distances for the field storage categories (regulation 16-5-4, Section 63b.):

- exterior Q-Ds from ammunition store to fuel store, field hospital, command post and equal units/installations should be at minimum 500 metres;
- exterior Q-Ds from piles containing rockets and guided missiles should be at least 850 metres.

The minimum interior Q-Ds as presented in regulation 16-5-4, Section 126, are almost similar to TM 9-1300-206. Although the Norwegian regulations present more information on the subject, they are not consistent on several points:

- the regulation 16-5-4, Section 63, also presents interior Q-Ds, which differ significantly from those presented in Section 126;
- regulation 16-5-4, Section 63, prescribes a minimum distance between ammunition trucks of 25 metres, and it says that two trucks can be parked close together. Regulation 16-5-2, Section 107, prescribes a distance between loaded ammunition vehicles of at least 50 metres.

Because the sections of the Norwegian regulations, available to TNO-PML, contain inconsistent information, they are not evaluated with the case as defined in Section 3.2.

4.5 Discussion in AC/258 Storage Subgroup

In reply to the concerns of the Netherlands Key Delegate of the AC/258 Storage Subgroup regarding UN Logistics Directive 312, a discussion in the AC/258 storage subgroup was initiated. In this section, the IWPs on this subject are summarized and discussed.
The members of the AC/258 group were asked to present their national field storage regulations or point of views on this subject. So far, reactions from Norway (see previous Section 4.4), Canada and Germany have been received by means of the following informal working papers:

1	NO (ST) IWP 1-95	(dated 13 March 1995).
2	AC/258 (ST) CA-IWP/1-95	(dated 17 March 1995).
3	AC/258(ESG)(ST)IWP 1-95	(dated 16 August 1995).

ad 2.
This paper gives the Canadian point of view regarding field storage during UN missions. The Canadian IWP suggests a minimum safety distance based on the $D=9.6Q^{1/3}$ function with a minimum of 200 metres. This is the same function as accepted by the RNLA and RNLAF. As mentioned earlier, this protection level should give sufficient protection against blast effects of an accidental explosion involving HD 1.1. At this quantity-distance, personnel might suffer non-permanent injuries such as temporary hearing loss. Protection against the impact of fragments and debris can be achieved by constructing barricades around a storage facility or using shelters with overhead protection as a storage facility. It is stated in the paper that this criterion would be suitable for sleeping accommodation.
For ES such as POL installations, hospitals and airfields, the paper suggests the use of the quantity-distance $D=22.2Q^{1/3}$ (D13 in AASTP-1) or $D=14.8Q^{1/3}$ (D11

in AASTP-1) with a minimum of 400 metres. The civilian population should be provided with a minimum safety distance of D13 with a minimum of 400 metres. Besides these quantitative suggestions, the paper gives some other interesting remarks.

a 'Operational concerns will often dictate the conditions under which ammunition storage is accomplished. In most cases, circumstances are far from ideal and Commanders must make their decisions after weighing various conflicting factors: the two most prominent being ammunition safety and physical security. Therefore, any recommendation that we might eventually make as a group must take into account the Field Commander's prerogative to adapt to the operational situation even if this means accepting a higher level of risk';
b 'The basis upon which safety criteria are founded are: the survival of the troops is paramount; the survival of other resources is vital to the conduct of operations; the effects from an accidental explosion must be minimized; and Commanders must retain operational flexibility';
c 'The types of sites that require protection are: sleeping accommodation; airfield, hospital, POL installations, civilian population; and other explosive storage sites';
d 'Safety separation within the ammunition area should be based on guidelines similar to what is contained in the AASTP-1 manual for field storage. Ammunition in different compatibility grouping must be segregated according to current rules and the separation between each site must be sufficient to prevent instantaneous propagation. The use of barricades will be essential not only to reduce separation distances but as a mean to protect the ammunition against enemy fire';
e 'Circumstances surrounding a particular mission may be such that the recommendations made cannot be adapted. Therefore, our recommendations should contain sufficient information to properly inform Commanders about the risks they are willing to accept'.

ad 3.
Is a formal version of the Canadian IWP. The German IWP is a, somewhat revised, version of the Canadian paper with the aim to publish it as a formal WP.

4.6 General conclusions on standards

In this chapter, explosives safety standards, which include regulations for field storage of ammunition and explosives, are consulted and evaluated. The conclusions which can be drawn from this literature survey are diverse. For the NATO AASTP-1 and American DoD6055.9-STD standards, the main conclusions are:

1 both standards include well-considered regulations for permanent storage in the interior zone during peacetime;
2 the explosion safety principles specifically for field storage are not applicable for the Field Commander;

3 both standards state that a higher level of risk is accepted for field storage in the theatre of operations. However, a clear quantification of this increase of risk is not given. Moreover, it is shown that certain prescribed minimum quantity distances are larger in the case of non-permanent field storage out of area than in the case of permanent storage in peacetime;
4 none of the standards give direct information on the consequences regarding explosion safety in case a Field Commander has to deviate from the standard regulations;
5 the applied UNO hazard classification system, which categorise the ammunition and explosives into Hazard Divisions and Compatibility Groups, is not very suitable for use in the field. The system is too detailed and introduces too many variables in the determination of minimum required stand-off distances.

The United Nations Organisation formulated their own directives for field storage of ammunition and explosives. The following conclusions can be drawn from Logistics Directives 312 (two versions), 100 and 101.
1 In contrast to the above-mentioned standards, the procedures prescribed in the Logistics Directives are very straightforward.
2 The UNO classification system is simplified to two hazard classes. These are 'small arms ammunition and pyrotechnics' and 'high explosives'. Stand-off distances are given for these two ammunition and explosives descriptions. This simplification is welcome.
3 However: exact definitions of both hazard classes are not included;
4 logistics Directive 312 (dated 20 March 1993) does not mention maximum quantities allowed for the given stand-off distances;
5 all prescribed stand-off distances of storage areas to exposed sites are significantly smaller than prescribed by the NATO AASTP-1. The references of the procedures and the policy regarding the accepted level of risk is not mentioned;
6 Logistics Directive 101 copied some recommendations from the NATO AASTP-1. However, some data is copied incorrectly, which can result in dangerous situations.

The basic difference between the standards on explosive safety principles and the UN Logistics Directives is that the former ones are too detailed and impractible for Field Commanders, and the latter ones give too little information and accept a higher level of risk.

5 Introduction to the next phases of the project

In this first interim report, current regulations on field storage of ammunition and explosives are evaluated and the problems and shortcomings are inventoried. Also, the basic demands and needs of the RNLA and RNLAF are listed. In this chapter, a research proposal for the next phase(s) of the project is presented.

In the second phase of the project, preliminary guidelines will be formulated on the basis of the results of this first interim report. With the risk level as defined and accepted by the RNLA and the RNLAF, consistent and more accessible and user-friendly field regulations will be formulated. They will be a compromise between the impractical NATO AASTP-1 regulations and the insufficient and inadequate regulations prescribed by the UN. These preliminary guidelines will emphasize explosion safety principles and the accessibility and user-friendliness.

However, with the current available storage facilities and protective measures, it is expected that the resulting required minimum stand-off distances are more or less unacceptable for Commanders in the field. The ultimate goal of the project is to find an optimal compromise between explosion safety factors and military applicability. For the third phase of the project, it is therefore proposed to adapt the preliminary guidelines on the military applicability and flexibility. This project approach is presented graphically in Figure 3.

There are several options to edit the preliminary guidelines in order to reduce stand-off distances and therefore increase the military applicability (phase 3 of project):

1 adapt storage concept;
2 adapt standard TEU-container;
3 develop more effective protective measures;
4 adapt the accepted level of risk.

ad 1. Storage concept

A modular concept is defined in which one storage module is defined as one TEU-container filled with ammunition and explosives with an NEQ of between 500 kg and 5000 kg. If further compartment of the ammunition and explosives inside the TEU-container is practically possible, stand-off distances can be reduced. A radical way to reduce exterior stand-off distances is to define smaller modules (i.e. 10 ft containers) and thus smaller NEQs. However, to store the same total NEQ of ammunition and explosives, the resulting storage site will be larger, since minimal intermagazine distances have to be observed.

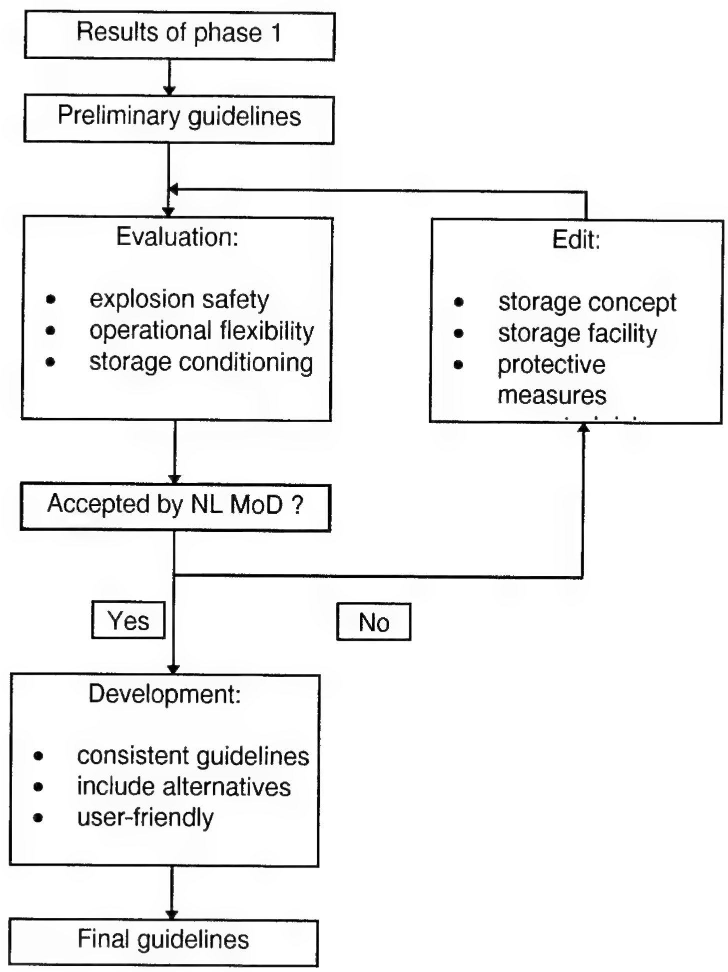

Figure 3: Project phases.

ad 2. TEU-container

Besides the possible development of specific compartment facilities in a TEU-container, the standard TEU-container itself can be adapted. During the transport and cantonment phase, the containers and the stored goods are vulnerable to enemy fire. Some ammunition and explosives are sensitive to perforation by projectiles, introducing a chance of an (mass) explosion. Although the chance of being hit is small (because of the short time of exposure), it can be considered to protect the stored goods against small arms ammunition by applying mobile lightweight protective panels inside the container.

ad 3. Protective measures

Current barricades for field storage facilities concentrate on the protection against horizontal (internal and external) threats. Examples are sandbag constructions, big bags and the Hesco Bastion defence wall system. Protective roof constructions are

normally not applied, but should be included. As concluded from the evaluation, explosion hazards are specifically expected from projections. It is desirable to develop measures to reduce these projection hazards as well as the air blast and thermal radiation. It is obvious that these measures must be military applicable.
A possible method to reduce explosion effects to the environment is to (partially) bury the storage container and/or to cover the facility with earth. However, it is expected that standard TEU-containers cannot withstand the static load induced by a top-layer of earth. The doors of a standard container are easily jammed by such static loads.
International research (especially by the National Defence Research Establishment, FOA, Sweden) into measures which reduce explosion effects, show optimistic results with so-called waterbags. With preliminary experiments, it has been demonstrated that when high explosives are surrounded by bags filled with water, the air blast and projections will reduce significantly. This concept may be applicable for field storage facilities.

ad 4. Accepted level of risk
In case the above-mentioned aspects do not provide the desired reduction of stand-off distances, a higher level of accepted risk has to be accepted in case greater exterior stand-off distances cannot (or will not) be observed.

In cooperation with the RNLA and RNLAF, priorities to these options must be indicated.

6 Conclusions

On behalf of the RNLA and RNLAF, TNO-PML has started a research programme to develop directives for safe field storage of ammunition and explosives for military operations out of area. This interim report presents the results of the first phase of the research programme in which:

1. the problems expected on developing future field storage regulations are inventoried;
2. the specific needs and demands of the RNLA and RNLAF are formulated;
3. the current international field regulations are evaluated;
4. the next phases of the project are introduced.

ad 1.
The factors affecting the explosion safety and therefore the level of risk in and around a field storage site are summarized. The major factors are the minimum required interior and exterior stand-off distances, which determine the damage and injuries in case of an explosion of one of the storage facilities. For the accepted level of risk, these minimum stand-off distances required are often not military applicable. Field Commanders want to store their basic load ammunition inside a cantonment, while explosion safety principles prescribe minimum distances requiring a separate field storage site.
Another important aspect in the development of future regulations for field storage is that they should include sufficient information about the consequences, regarding the level of risk; for these situations standard regulations cannot be observed. Current directives do not include such information. In future directives, it is desirable to present this additional information in a graphical format to make it more accessible for users in the field.

ad 2.
The RNLA and RNLAF defined an accepted level of risk to be implemented in future regulations for field storage. This level of risk is relatively low.
Secondly, they proposed a modular storage concept in which TEU-containers are used as basic storage facilities containing ammunition and explosives with a net equivalent quantity varying between 500 kg and 5000 kg.

ad 3.
Current regulations for field storage of ammunition and explosives are evaluated with a case study. In general, safety standards for ammunition and explosives, like the NATO AASTP-1 and the U.S. DoD6055.9-STD, are much too detailed and not suitable for use in the (battle)field. The standards are far from user-friendly and the information focuses on permanent storage in peacetime. On the contrary, Logistics Directives from the UN present a lack of information. The prescribed guidelines are straightforward in use, but are sometimes inconsistent and insufficient.

ad 4.

It is proposed to formulate preliminary guidelines which emphasize explosion safety principles and accessibility and user-friendliness. However, for future regulations on field storage of ammunition and explosives, it is vital to implement explosion safety principles which minimally affect the military operational flexibility. Therefore, options to reduce stand-off distances are proposed for further investigation in the third phase of the project. They include the compartment of ammunition and explosives in a storage facility and the development of more effective protective measures.

To make future regulations more accessible and user-friendly, TNO-PML proposes the reconsideration of the Hazard Divisions as normally used for storage of ammunition and explosives. For example, HD1.2 and 1.3 could be considered as HD1.1. Although this simplification results in less regulations (i.e. Q-D tables), it will increase minimum required interior and exterior stand-off distances.

7 References

[1] AASTP-1 Edition No. 1. Manual of NATO safety principles for the storage of military ammunition and explosives. May 1992.

[2] Air Force Manual 91-201. 7 October 1994.

[3] Assheton, R.,
History of explosions on which the American Table of Distances was based. Published under the direction of the Institute of Makers of Explosives. Charles Story Press Co. Wilmington, Delaware, 1930.

[4] Baket, W.E. et al.,
Fundamental studies in engineering 5. Explosion hazards and evaluation. Elsevier scientific publishing company, 1983.

[5] Directie Materieel Koninklijke Landmacht. Naam- en Codelijst NC 9-65. Munitie en overige klasse V-goederen. Versie 31 juli 1995.

[6] DoD 6055.9-STD. DoD Ammunition and Explosives Safety Standards. October 1992

[7] Jarret, D.E.,
Derivation of the British explosives safety distances.
Annals of the New York Academy of Sciences, 152, Article 1, pp.18-35 (October 1968).

[8] Healy, F.; Major, R.A., Secretary, E.S.T.C.,
Notes on the basis of outside safety distances for explosives involving the risk of mass explosion. Adopted by the inter-departmental explosives storage and transport committee of the United kingdom in 1948. March 1959.

[9] Joint Munitions Effectiveness Manual 61A1-A-A-3-2. Air-to-surface. Weapons Characteristics (JMEM) (U). Revision 4-11 February 1994.

[10] MP 40-20,
Voorschrift opslag en vervoer explosieve stoffen en munitie. Februari 1995. TNO-PML Docnr. D90-0705.

[11] Naamlijst munitie en explosieven van de KLu (3e Herziene uitgave). Pubnr. 35038. (16 juli 1991).

[12] Pelton, Capt. J.F.,
Operation GRAPPLE. Hardening aide memoire, edition 2. 15 April 1994.

[13] Pieterse, G.J. and Buren, B. van,
KMA Verslag Meppen 1990. TNO-PML documentatienr. D91-0578.

[14] TM 9-1300-206. Technical Manual Ammunition and Explosives Standards.
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8 Authentication

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

On behalf of the RNLA and RNLAF, guidelines for safe field storage of ammunition and explosives for military operations out of area will be developed. In this first project phase, the shortcomings of current (international) directives are inventoried and a list of specific demands and wishes of the RNLA and RNLAF is formulated. The acquired knowledge and information will be used in the second phase of the project to develop preliminary guidelines. After evaluation of aspects such as explosion safety and military applicability, final guidelines will be formulated.
The current directives for field storage are not suitable for military use. The NATO AASTP-1 standard prescribes well-founded regulations, but is not very accessible and therefore not suitable for use in the field. The military directives of the UN are inconsistent and incomplete. The offered level of protection for personnel and environment is significantly lower than according to the NATO standard.
An accepted level of risk is defined by the RNLA and RNLAF. It is expected that the implementation of this relatively low level of risk in future guidelines will affect the military applicability.
Measures to reduce exterior stand-off distances to increase the military applicability are discussed.

16. DESCRIPTORS	IDENTIFIERS
Ammunition	
Explosives	
Military operations	
Safety	
Recommendations	Standards

17a. SECURITY CLASSIFICATION (OF REPORT)	17b. SECURITY CLASSIFICATION (OF PAGE)	17c. SECURITY CLASSIFICATION (OF ABSTRACT)
Ongerubriceerd	Ongerubriceerd	Ongerubriceerd
18. DISTRIBUTION AVAILABILITY STATEMENT		**17d. SECURITY CLASSIFICATION (OF TITLES)**
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3 DWOO

4 HWO-KL

5* HWO-KLu

6* HWO-KM

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8 DMKLu
Maj. J. Paap

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17 TNO-PML, Hoofd Divisie Munitietechnologie en Explosieveiligheid
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21 TNO-PML, Documentatie

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